SUBGLACIAL SEDIMENT DEFORMATION IN HELLAS BASIN: TESTING A POSSIBLE ORIGIN FOR THE BANDED TERRAIN. C. W. Cook[1], S. Byrne[1], [1]Lunar and Planetary Laboratory, University of Arizona, Tucson, AZ 85721 (clairec@lpl.arizona.edu)

Introduction: The extent of past glaciation on Mars is an important unknown in determining its water inventory and climate history. Understanding the origin of the banded terrain in Hellas basin could shed light on this aspect of martian history. Banded terrain, located in northwest Hellas, is composed of smooth bands separated by ridges or troughs with linear, lobate, and circular forms (Fig. 1 a–c) [1, 2]. Bands are typically ~5 km long, ~300 m wide, and ~10 m in relief [2]. Its age has been loosely constrained to ~1.9 to 3.7 Gyr. In some locations, banded terrain superposes honeycomb terrain, which is made up of adjacent ~10 km wide depressions [3] (Fig. 1 d).

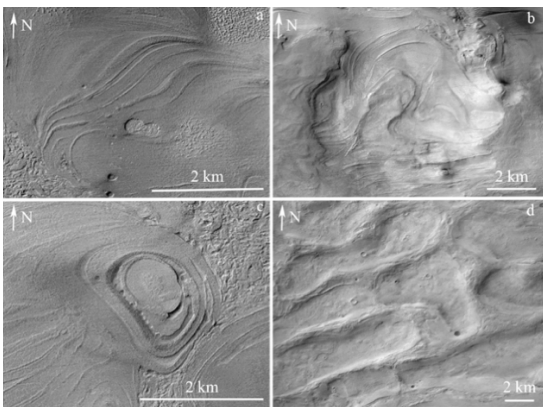

Figure 1: Examples of a) linear banded terrain, b) lobate banded terrain, c) circular banded terrain, and d) honeycomb terrain. CTX image D21_035353_1431.

Several hypotheses have been advanced to explain the banded terrain, including flow of a thin ice-rich layer. However, comprehensive measurements by Bernhardt et al. [1] suggested that band orientation does not have a consistent correlation with local slopes. They hypothesized that spatially-varying small-scale stresses resulting from a thick ice sheet in conjunction with basal topography like the honeycomb terrain may have deformed subglacial sediment into the complex patterns exhibited by banded terrain. However, while terrestrial subglacial bedforms can exist at a similar scale to banded terrain [4], their morphology differs, challenging their interpretation as an analogue.

Here, we perform quantitative modeling to test the hypothesis that banded terrain may be formed by subglacial sediment deformation. First, we model the surface velocity of a hypothetical thick ice sheet in western Hellas over the banded terrain region. We then use a model with higher-resolution basal topography to test whether this deformation rate can reproduce the relief, scale, and shape of banded terrain.

Methods: Ice and subglacial sediment deformation are simulated using the finite element modeling software COMSOL. We use the Ice Sheet System Model (ISSM) [5] to make the mesh and verify the COMSOL results (though only for a case without subglacial sediment). The model consists of two parts. One part is a large-scale, low-resolution model of an ice sheet in Hellas, used to find the velocity at the ice surface. The second part is a small-scale, higher-resolution model of subglacial sediment and ice with the surface velocity prescribed from the large-scale model.

To test if subglacial sediment deformation is a reasonable mechanism to form the banded terrain, we first assess the conditions most conducive to its success. The results of this can guide further inquiry into the limits of conditions that might allow for banded terrain formation. The ice surface for our standard case of a Hellas basin ice sheet is prescribed such that it maximizes the ice velocity over the banded terrain region by maximizing surface slope and thickness there.

Ice rheology is modeled using a viscous flow law: $\dot{\varepsilon} = Ae^{-2n\varphi}e^{-Q/RT}{\tau_E}^{n-1}\tau d^{-p}$ where $\dot{\varepsilon}$ is the strain rate, A is the rate factor, n is the stress exponent, φ is the dust volume fraction, Q is activation energy, R is the gas constant, T is temperature, τ_E is the effective stress, τ is the deviatoric stress, d is the grain size, and p is the grain size exponent [6]. We combine strain rates from dislocation creep, grain boundary sliding, and basal slip deformation mechanisms, with different parameters (A, n, Q, p) for these three modes [6]. Terrestrial tills have been described in many studies as Mohr-Coulomb plastic [7]. However, below the yield strength, till may undergo nonlinear creep [7]. Our tests of a sediment layer with a plastic yield strength consistent with terrestrial subglacial till showed that the yield strength was not exceeded anywhere at the base of the ice sheet. Therefore, we instead use a viscous creep rheology (as in [8]) of the form: $\dot{\varepsilon} = A_s{\tau_E}^{n_s-1}\tau$ where A_s is the sediment rate factor and n_s is the sediment stress exponent.

The parameters for our baseline model are a surface temperature of 200 K, basal heat flux of 30 mW/m^2 [9], dust content of 10%, based on the upper limit of dust content estimated for mid-latitude debris-covered glaciers, e.g., [10]), and sub-glacial sediment layer thickness of 30 m (based on banded terrain relief measurements [1, 2]). The sediment rheology is moderately nonlinear (n_s=3). The sediment rheology rate factor is not well constrained, and we vary it between a value consistent with viscosity measured for partially-frozen terrestrial till (~3×10^{12} Pa s) [11] and a value consistent with ice at 200 K.

The basal topography for the lower resolution models is from MOLA. For the higher resolution models of subglacial sediment, the basal topography will be based on CTX or HiRISE stereo DTMs of units superposed by banded terrain or simulated topography that mimics these units.

Results: Figure 2 shows the magnitude of horizontal velocity at the base of the ice sheet for one case, with low viscosity sediment ($A_s=10^{-22}$ Pa^{-3} s^{-1}; consistent with partially frozen terrestrial till). The average velocity at the ice-sediment boundary in the banded terrain region is ~0.5 m/yr, and the velocity at the ice surface is ~1.3 m/yr. If the sediment rheology is set to match the ice rheology, the velocity at the ice-sediment boundary is ~0.04 m/yr and the velocity at the ice surface ~0.75 m/yr. The high average velocities are consistent with estimates based on the slope and thickness of the prescribed ice sheet geometry.

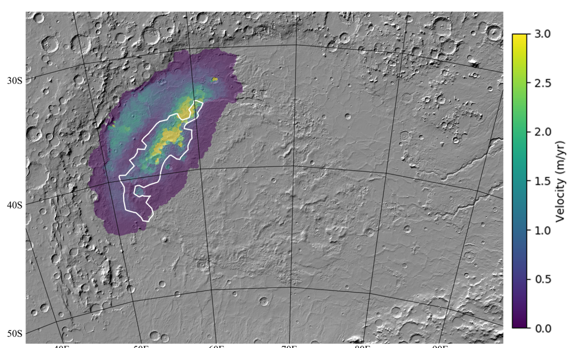

Figure 2: Top-down view of an ice sheet in Hellas basin, showing the horizontal velocity magnitude at the ice surface after 100 years. White outline shows the banded terrain region.

Figure 3 shows the vertical displacement after 100 yrs at the surface of a 30m-thick sediment layer in the small-scale model. In this case, the sediment was low-viscosity and the initial sediment-ice interface was flat with sediment-basal-topography relief of 10–20 m. Ridges form that follow parts of the basal topography, with the ridge orientation approximately perpendicular to ice flow direction. After 100 years, the relief of these ridges (vertical displacement at the surface) is ~1 m. At this rate, it would take ~1000 years to form ridges with the observed banded terrain relief of ~10 m (well within the timescale of an obliquity cycle, for instance), though this rate may change as ridge formation proceeds.

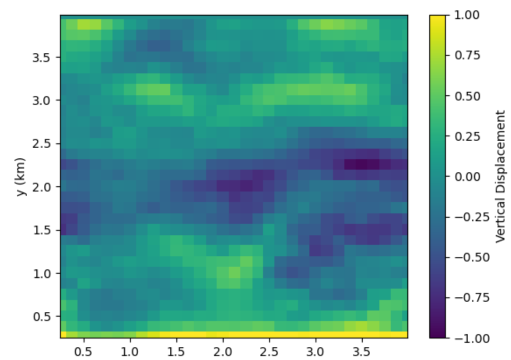

Figure 3: Top-down view of the sediment surface, showing the vertical component of displacement after 100 years. Velocity at the ice-sediment interface is 1 m/yr. The basal topography is a random noise surface with a root mean square roughness of 5 m (for a baseline of 8 m) and a fractal dimension of 2.

We will do further tests of sediment deformation using basal topography from DTMs and consider cases where the sediment surface does not exceed the maximum elevation of the basal topography everywhere (so that e.g., honeycomb cell rims may provide an obstacle to sediment deformation). We will test whether sediment deformation can form ridges with multiple orientations from an ice sheet with a single flow direction, depending on the basal topography and initial sediment surface.

Our results so far indicate that sediment deformation into ridges is possible beneath Martian ice sheets. The relief of the ridges depends mainly on the ice flow velocity and ridge orientation depends on ice flow direction as well as the basal topography. This velocity, determined from the larger-scale ice sheet model, depends mostly on the sediment viscosity and basal temperature. Future work will further explore the effect of basal topography and the initial sediment surface on resulting deformed sediment morphology and further explore the parameter space to determine what range of conditions may explain the observed banded terrain.

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